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Groundwater Hydrograph Patterns in North China Plain during 1982-1986 Interpreted Using Principal Component Analysis

Ruigang Zhang[1,a]

[1] Key Laboratory of Water Cycle and Related Land Surface Processes, Institute of Geographic Sciences and Nature Resources Research, Chinese Academy of Sciences, Beijing 100101, China

[a]zrgang@yeah.net

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Abstract. The groundwater depths of 58 unconfined wells in North China Plain(NCP) from 1982 to 1986 were analyzed using principal component analysis method. Results showed there were mainly three hydrograph patterns over the area: increasing trend with steady moderate seasonal fluctuations in Taihang Mountain piedmont area; decreasing trend with large seasonal fluctuation magnitudes in central plain of NCP; increasing-decreasing trend with large variance of fluctuation magnitude in piedmont of Yan Mountain piedmont.The distribution of precipitation, irrigating abstraction, and groundwater depths were the main factors determining the hydrograph patterns and their distribution.

Introduction

The North China Plain (NCP) is one of China's most important social, economic, and agricultural regions [1]. Sustainable development depends heavily on groundwater resources in the area. A lot of researches from regional to local scale have been carried out to study the groundwater dynamics and manage the groundwater resources. For example, in regional scale, Wang et al. [2] analyzed the water level dynamics of 39 wells that distributed over NPC during 2004-2006. They interperted the groundwater fluctuation features of various dynamic patterns, and compared the influencing factors of the patterns. In local scale, Qian et al. [3,4] using modeling approach to assess the aquifer paramters and sustainable pumping rate in Zhangji well field; and to find optimal strategy for spring protection in Jinan city in China.

To have a general picture representing the dynamics of groundwater depths as well as their distribution nature over the region would help understand and manage the groundwater resources of the area. In this study, principal component analysis was attempted to investigate the shallow groundwater depths data (well depths were all smaller than 60m, most were between 10-40m) over period of 1982-1986 when relatively abundant observations are available to reveal general patterns as well as their influencing factors for the region. Because the observations in recent years are very sparse, the interpretation of historical groundwater depth dynamic patterns and their distribution is also significant to help analyze groundwater dynamic information more accurately in recent years, and help to understand the evolution of the hydrograph dynamic patterns.

Study area

The NCP located in eastern China between 112°30′–119°30′E and 34°46′–40°25′N is bounded by the Taihang Mountains to the west, the Yanshan Mountains to the north, the Bohai Sea to the east, and the Yellow River to the south, covering a total area of approximately 140,683 km^2. It includes all the plain area of Beijing, Tianjin and Hebei Province and the plain area of Henan and shandong provinces to the north of the Yellow River. From the foot of the mountains to the Bohai Bay, it can be divided into the piedmont and flood fan plain of the western part, central flood plain of middle part and the littoral plain of the eastern part (Fig. 1). The climate of NCP belongs to the continental climate [2].

Methods

Principal Component Analysis (PCA) is a multivariate statistical procedure which is commonly used to reveal patterns in large data sets through determining a few linear combinations of the original variables that can be used to summarize the data set without losing much information. The method decomposes the correlation or covariance matrix of a dataset into a scores matrix and a loadings matrix by calculating and scaling eigenvectors and eigenvalues. Component loadings are effectively a measure of the similarity between each original variable and each principal component [5], while the component scores are a measure of the similarity between cases and each principle component.

Groundwater depths data of 58 wells covering Hebei province area in NCP during 1982-1986 were analyzed using PCA method. For the special application, component loadings are a measure of spatial similarity between the groundwater depth variables and each principal component, while component scores are a measure of the temporal similarity between the observed pattern of groundwater depths for a given date and each principal component [6].By relating the hydrographs of each individual well to the graphs of components based on their correlations determined by component loadings matrix, the areal distribution of hydrograph patterns could be mapped throughout the area. Also, it is believed that this type of information would be useful in understanding and analyzing the influencing factors of the patterns of groundwater depth dynamics.

The analysis process of this study is similar with reference [6] in which PCA method was used to provide insights into characteristics of groundwater recharge, effect of surface water and differences in geologic properties on water table fluctuations. Furthermore, standardized groundwater depth data was used to plot the “true” groundwater hydrographs in this paper, so that the results between hydrographs and the components scores hydrographs could be more comparable.

The PCA procedure is described in numerous statistics books and is included in most statistical software package. In this study, SPSS (version 17.0) software was used to perform the analysis.

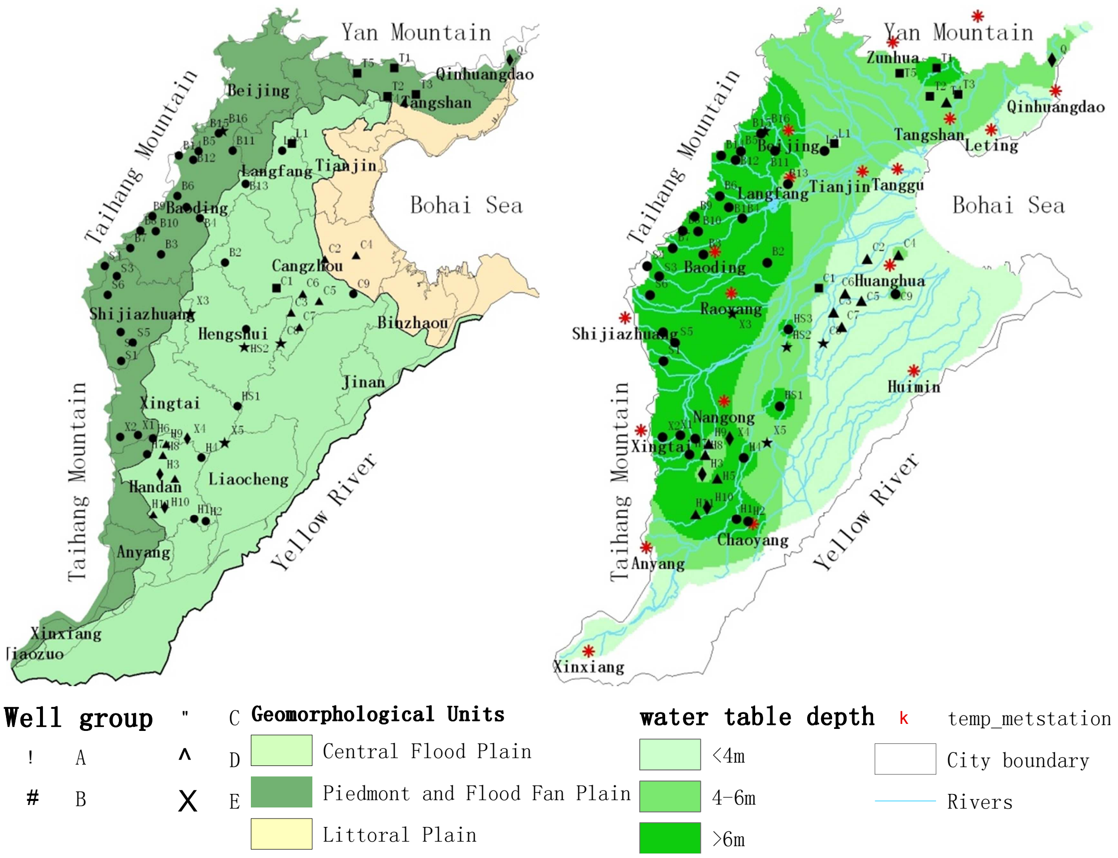

Fig.1 Areal distribution of well groups, as delineated in Fig. 2 for the NCP, and configuration of averaged groundwater depth during 1982-1986

Results and discussion

The first three components accounted for 51.0%, 16.5%, and 10.1% of the variance in the groundwater depth data, respectively, and accumulative amount of 77.6%. Given that component 1 to 3 captured most information of the variances, furthermore, nearly all the component loadings of which after component 4 are smaller than 0.5, only component 1 to 3 were analyzed thereafter. In other words, three main hydrograph patterns corresponding to the first three principal components were revealed and interpreted in the followed part. The temporal variances of the components are showed in Fig. 3 Hydrographs in the figure refer to herein as scores hydrographs.

For ease of visualization, the component loadings for each well as they relate to PC1 versus PC2 (see Fig. 2) was plotted (these two components accounted for 67.5% variances in the water level data) in a two dimension diagram with ignoring information of component 3. However, the wells that had higher loadings on component 3 than on others were symbolized specially as group C in Fig. 2.

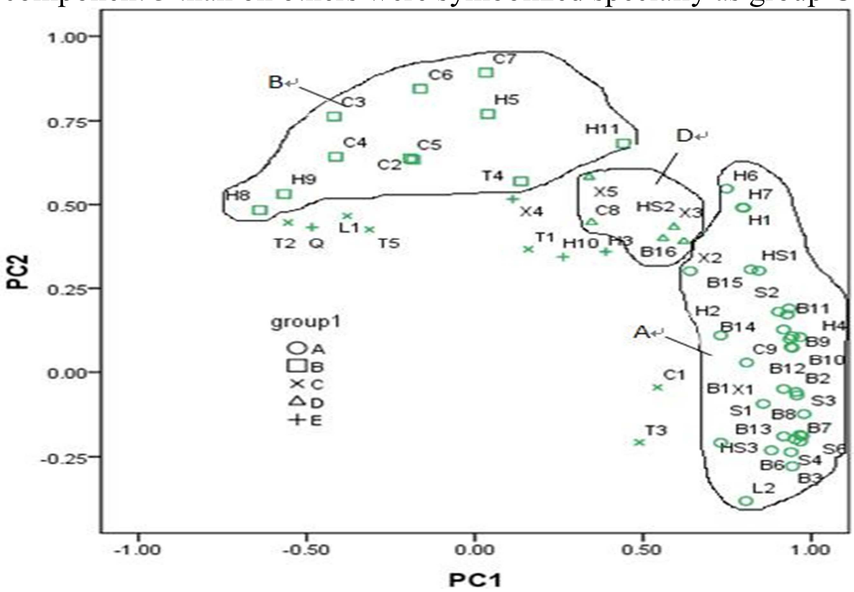

Fig. 2 Scatter plot of component loadings for principal component 1 versus component 2 for groundwater depths in NCP.

The Fig. 2 indicates that most of the wells fall into several groups. A large number of wells that have high loadings on PC1 and low loadings on PC2 on the lower right side of the diagram are designated as Group A. Another group of wells with relatively higher loadings on PC2 and lower loadings on PC1 on the upper right side of the diagram were designated as group B. Group C are those wells that has higher loading on PC3 than on others. Those located between group A and B with low loadings on both PC1 and PC2 were designated as group D, in which moderate relationship of the wells to both PC1 and PC2 were expected. Group E included the wells that had non-neglectable loadings on components besides the first three. Attention should be paid that group C and E could not be sorted from the diagram; they were identified through data table of component loadings, and showed in Fig. 2.

The variances in groundwater depths data include inter-annual variance over the five years and seasonal variance within each year. From Fig. 3 (a,c,e,g) we can see, the hydrographs all showed annual period fluctuations, but their inter-annual variance and seasonal fluctuation patterns are different. Despite the different seasonal fluctuation magnitude and various ‘shapes’, the seasonal changing processes of the hydrographs were nearly the same. The processes were dominant by those of agricultural abstraction and precipitation recharge. Winter wheat and summer maize are dominant agricultural productions over the area. The pumping for spring irrigation from March every year induced quick increase of grondwater depth until about June, when agricultural abstraction generally ceased. The groundwater depth then began to decrease until February of next year due to the effect of infiltration of rainfall and return flow of irrigation; in piedomont area, the mountain front lateral recharge also played an important role .

Differences between the three main hydrograph patterns are the variance of trend over years and seasonal fluctuation magnitudes. As shown in Fig. 1, most group A wells located in piedmont area of Taihang Mountain where groundwater in shallow aquifer was intensively abstracted for agricultural production. Hydrographs of standardized actual groundwater depths for two of these wells, S3&S6 (Fig. 3a) indicated the close relationship of these actual hydrograph patterns to scores hydrograph for PC1. This hydrograph pattern had a continuously increasing trend over the five years along with moderate, seasonal fluctuations. Fig. 3b showed a decrease trend of precipitation (Shijiazhuang station) around the area, which resulted in decrease of recharge and increase of pumping for agriculture, subsequently, caused the continuous increase of groundwater depths.

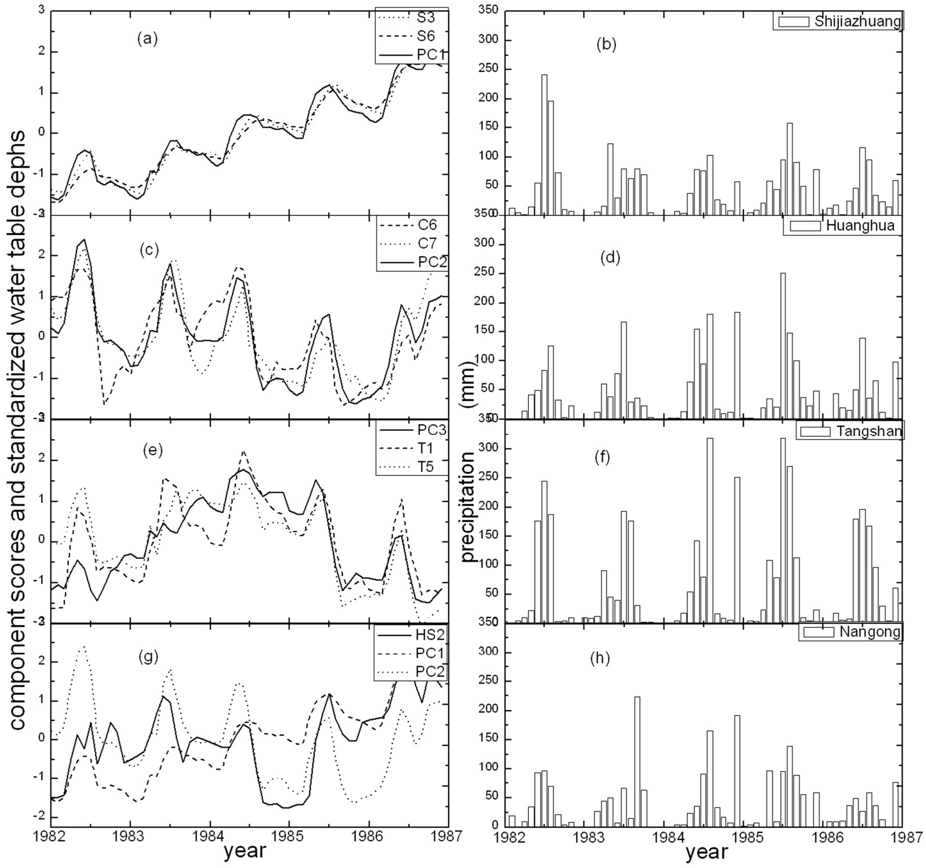

Fig. 3 Hydrographs and precipitation for NCP: (a) component scores for PC1, standardized groundwater depths in well S3 &S6; (c) component scores for PC2, standardized groundwater depths in well C6 &C7; (e) component scores for PC3, standardized groundwater depths in well T1 &T5; (g) component scores for PC1& PC2, standardized groundwater depths in well HS2; (b),(d),(f),(h) are precipitation in climate stations of Shijiazhuang, Huanghua, Tangshan and Nangong, respectively.

Group B wells with close relationship to PC2 mainly located in central plain and littoral plain (Figs. 1&2). Hydrographs in this pattern moderately decreased from 1982 to 1985, and likely turned to increase from 1986. The variance related closely to that of precipitation (Fig. 3d), relatively high precipitation during the first several years induced decrease of groundwater depth, while in the last year, the depths turned to increase because of low precipitation.

The seasonal fluctuations are relatively larger than that of group A and C, and the magnitude of fluctuations changed apparently over years. The sharp seasonal fluctuations related mainly to the shallow groundwater table (averaged groundwater depth of the studied years was mostly less than 4 meters as showed in Fig. 1). The shallow water table caused the quick response of groundwater depth to infiltration recharge, as well as the strong groundwater evapotranspiration.

Group C wells with close relationship to PC3 (Fig. 3e) mainly located in piedmont of Yan Mountain where the slope is large and the permeability condition of aquifer is good. The groundwater depths of group C increased from 1982 to 1984 and decreased from 1985 to 1986, which variance was consistent with the temporal variance of precipitation of the local area (Fig. 3f). The magnitude of the fluctuations varied largely both annually and seasonally. For example, hydrographs fluctuated gently in 1982, while sharply in 1985. Apparently, the sharp decrease of the groundwater depth in 1985 related to the large precipitation in that year. Because the water table was relatively deep (Fig. 3), we could deduced that the strong permeability of the aquifer and lateral recharge from mountain areas were important factors that caused the large fluctuation magnitudes besides the temporal distribution of precipitation.

Some wells showed equal similarity to hydrograph features of two or more principal components. For example, hydrograph of Well HS2 in group D (Fig. 3g) showed characteristics of the scores hydrographs for both PC1 and PC2(component loadings were 0.56 and 0.40, respectively), the groundwater depth of the well declined continuously over years like the variance of PC1, and the fluctuation magnitude were large like that of PC2. This may caused by the local situation that combined the hydrological feature and aquifer properties of those of group A and group B. Being close to the river (1.5km or so) might be one of the reasons.

Some wells showed particular hydrograph patterns influenced by very local complex conditions. Hydrograph of Well Q in Group E (Fig. 3e) located in Qinhuangdao, piedmont of Yan Mountain showed characteristics of the scores hydrographs for both PC2 and PC7 (component loadings were 0.43 and 0.53, respectively). PC7 only accounted for 2.1% of the total variance in the groundwater depth data, so it might reflected only very local information where Well Q located, because lack of information, this was not further interpreted.

Conclusions

Shallow groundwater depths in North China Plain during 1982 to 1986 were analyzed to get a general understanding of the dynamic patterns of the groundwater table over the region using principal component analysis method. The results showed:

(1)There were mainly three hydrograph patterns of groundwater depth over the area in the studied period: increasing trends with steady moderate seasonal fluctuations in Taihang Mountain piedmont area; decreasing trends with large seasonal fluctuation magnitudes in central plain of NCP; increasing-decreasing trends with large variance of fluctuation magnitude in piedmont of Yan Mountain piedmont. There were minor groups of wells showed other patterns influenced by local conditions that combined different precipitation, groundwater depth, aquifer properties, etc.

(2)The hydrograph patterns were dominated by spatial and temporal distribution of precipitation and irrigation pumping, which determined the basic temporal dynamics of the groundwater depth, as well as the distributions of the dynamics. Distribution of fluctuation magnitudes corresponded to that of precipitation intensity and groundwater depth.

Some phenomena need to be further studied when more detailed information such as longer observations of groundwater depth and detailed aquifer properties are obtained.

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